Calculating the radiation dose for a satellite platform.

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Abstract

1 Introduction

The Miniature Student Satellite (MIST) is a 3U CubeSat being designed and built by KTH students. Its launch is planned for 2019 and MIST should reach a sun-synchronous orbit at 640 km. At this altitude, the satellite will be exposed to radiations due to solar wind particles, energetic particles trapped in the Earth's geomagnetic field and galactic cosmic rays.

Considering that radiations can damage satellites, it is then necessary to take them into account when designing and conceiving them. The amount of radiations received con be modeled with Systema Dosrad, which is the Airbus Defence and Space legacy 3D sectorial analysis tool for radiation design. The analysis of the results is useful to highlight the need of protection shields and to adjust the size of some of the elements of the satellite.

2 Methodology

In this section it will be described the methodology used to prepare the simulation, along with the main assumptions which were made to simplify the model.

2.1 MIST model on SYSTEMA

We used the modeler included in *Systema* to reproduce a simple model of the satellite.

Figure 1 ,2 and 3 show the current state of the central part of the MIST satellite. Starting from the top, it is composed of:

- Propulsion experiment tank (yellow)
- Biological experiment tank (blue)
- Equipment heart (not visible on the figure)
- Batteries (pink)
- IRF experiment(green)

Mist also have solar panels on its sides and on two "wings" placed on each side. Although the solar panels are made of one thin layer ($< 1\,\mathrm{mm}$) of solar cells on top of few millimeters of aluminum, they were implemented in the program as 5 mm of Aluminum 2024.

Table 1 shows the main components along with their dimensions and the chosen material to model them in the simulation.

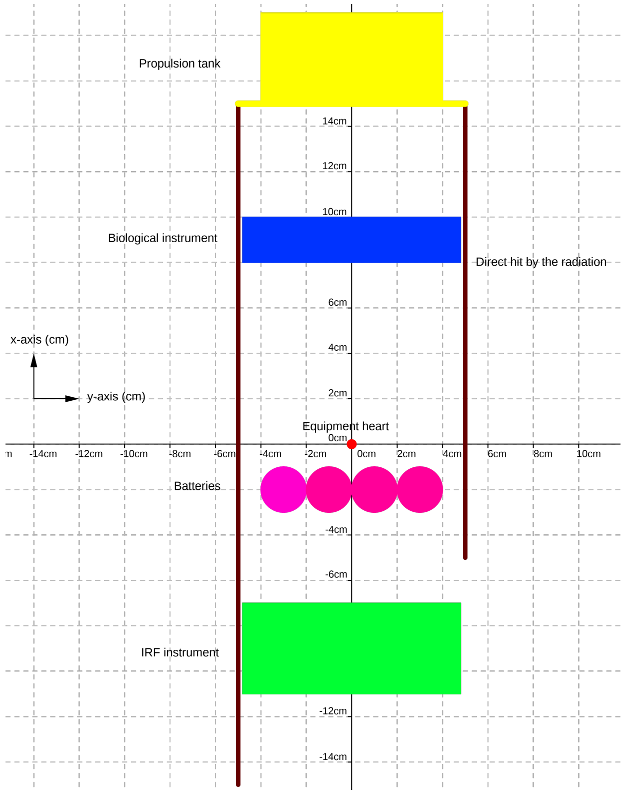


Figure 1: Profile view of the MIST model.

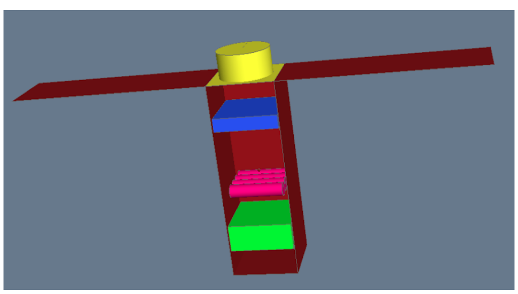


Figure 2: MIST model on Systema without front wall.

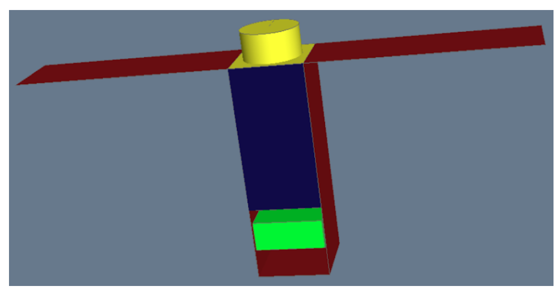


Figure 3: MIST model on Systema with front wall.

Component	**Dimensions**	**Thickness**	**Material**
Propulsion experiment tank	Cylinder with 8 cm diameter and 0.04 m height, with disc on top of it and a plate of 0.1x0.1 m^2 at the bottom	0.0015 m	TA6V
Biological experiment tank	Box of 0.02x0.096x0.096 m^3	0.002 m	Aluminum 2024
Equipment heart	Sphere with 4 mm diameter	0.001 m	Density: 4832 $kg \cdot m^{-3}$
Batteries	4 cylinders with 0.02 m diameter and height of 0.08 m	0.006	Aluminum 7075
IRF experiment	Box of 0.04x0.096x0.096 m^3	0.002 m	Aluminum 2024
Solar array (wings)			

Table 1: Caption

2.2 Dose depth curves

Dose depth curves represents the dose (rad) with respect to the Aluminum equivalent thickness at a constant altitude.

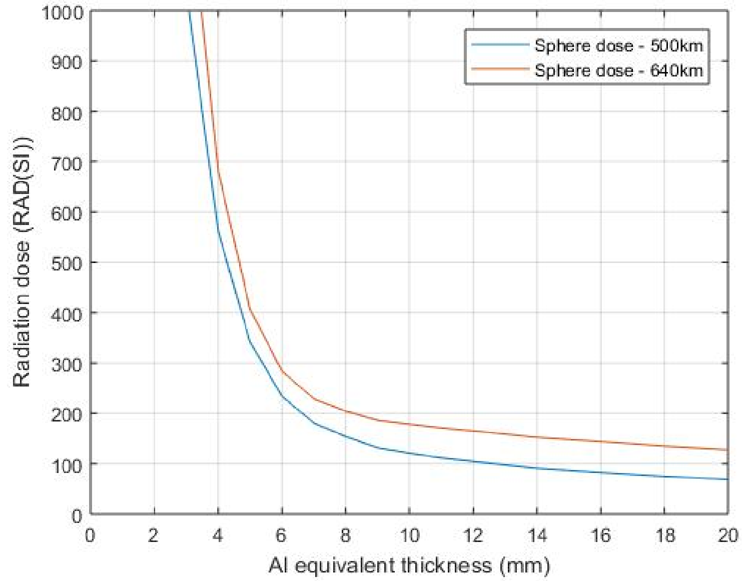


Figure 4: Radiation dose at 500km and 640km with respect to the Aluminum equivalent thickness.

As can be seen in figure 4, the radiation dose is always higher at 640 km.This can be explained by a more direct interaction with solar wind and cosmic radiations, considering that the density of the ionosphere is higher at lower altitude.

3 Results

3.1 Computer

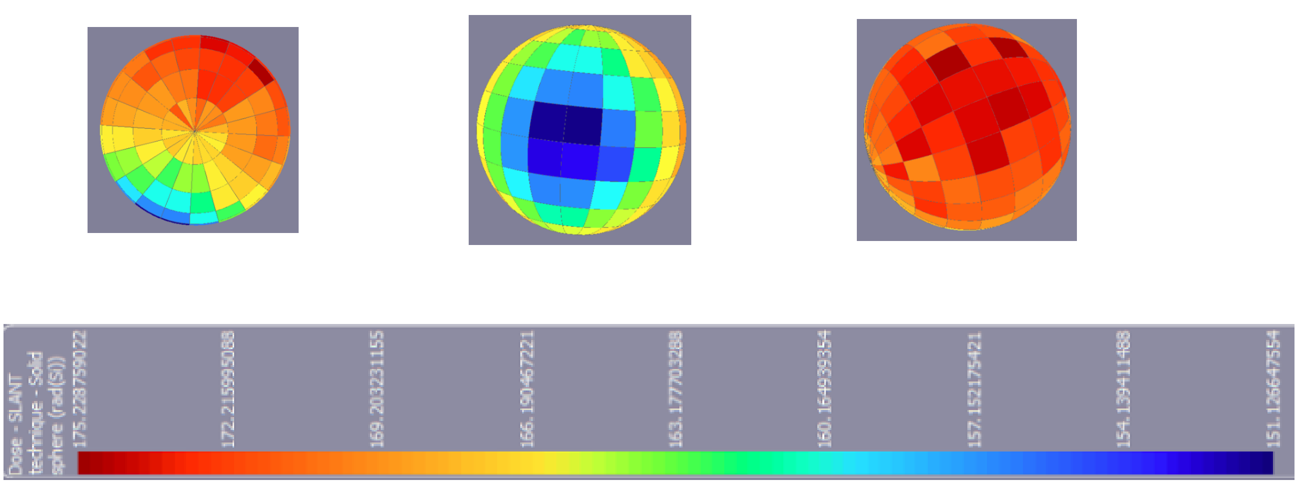


Figure 5: Radiation dose on the computer at 640 km.

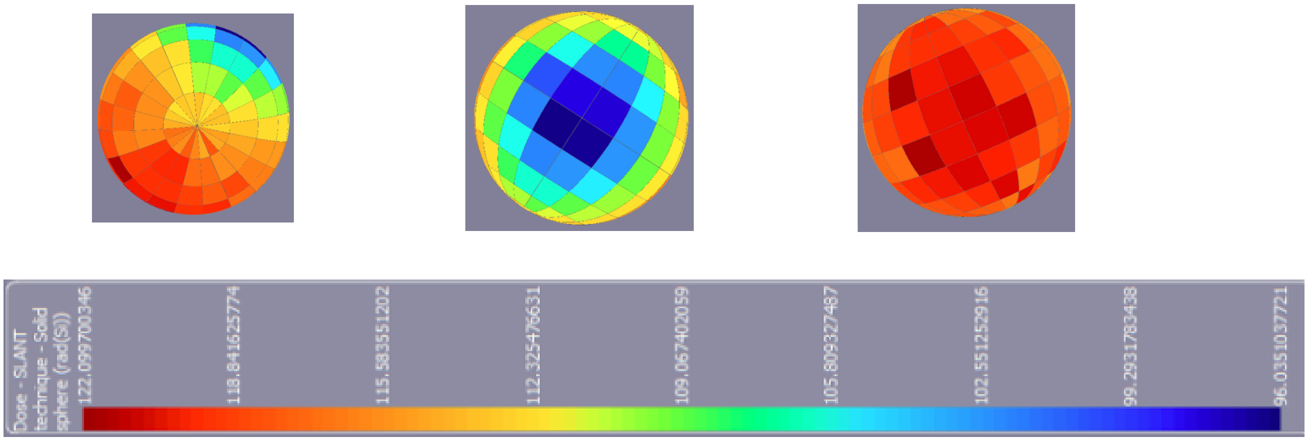


Figure 6: Radiation dose on the computer at 500 km.

3.1.1 Sun-synchronous orbit at 500km

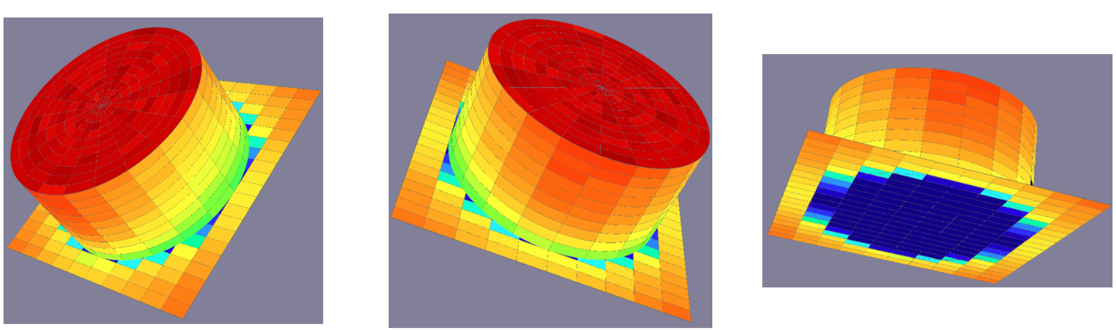
The OBC or On Board Computer is one of the most important parts of the satellite and is situated in the center of the satellite. The OCB has been modelled as a small sphere in order to understand the how the radiation affects the OBC processor from all direction. Althought the OBC is shielded by the satellite walls one can observe that the computer will be subjected to more radiation in the -X direction, due to the space opening around the IRF experiment. The radiation dose varies from the 175 to 151 Rad around the 640km altitude and from 122 to 96 Rad around the 500km altitude which is consistent with 4.

3.1.2 New results after adding Cubes

3.2 Propulsion

The propulsion tank is located at the top of the MIST satellite, the yellow part in figure 2. As can be seen in figure 7 the propulsion tank is exposed to high radiations at the top reaching values around 438500 rad, while the lower part is only exposed to around 600 rad. This is due to the shielding of the bottom of the propulsion tank by the parts underneath. Another interesting aspect seen in figure 7 is that the top cylindrical plate is subject to a lot higher radiation than the square plate underneath. This suggests that the radiation is coming from all angles, and that the square plate is shielded by the cylinder. As can be seen in table x the tank is modelled to be out of TA6V, a titanium alloy, this because of the exposure of higher radiations.

On the propulsion tank the shielding from the solar panels is also visible, lower radiation doses on the sides facing the solar panels and higher perpendicular to the wings.



3.3 Biologic Experiment

The biologic experiment part of the MIST is the blue part on the top of the satellite that can be seen on figure 2. The results for the radiation dose that this part receives at 640 km altitude can be seen on figure 8.

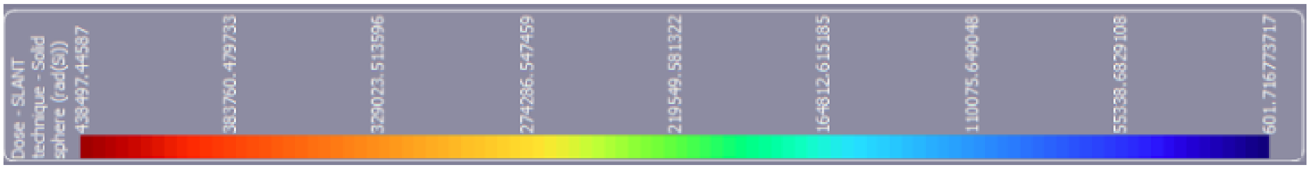


Figure 7: Radiation dose on the propulsion tank at 640 km.

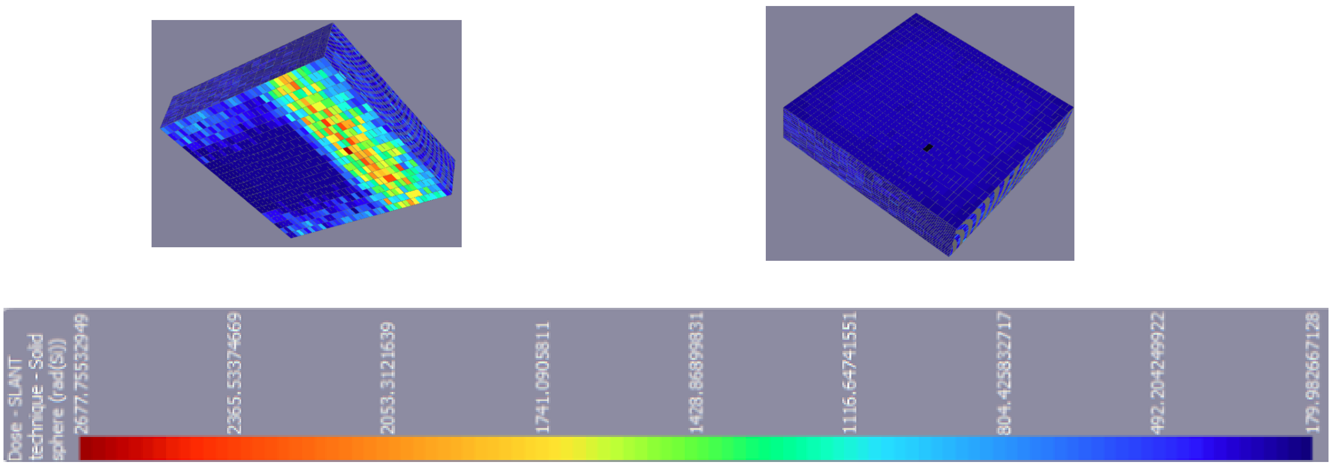
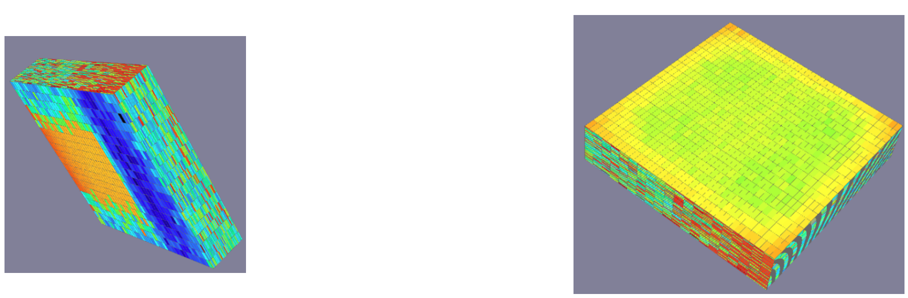


Figure 8: Radiation dose on the biologic experiment at 640 km.

The radiation dose varies from 179 to 2 677 rad.This is a large amplitude and figure 8 shows that the values are widely dispersed on the different surfaces. Considering this the meshing used on this part of the MIST was smaller than on the others to have a better view of the evolution of the radiation dose.

The distribution of the different amplitudes of radiation dose is interesting when considering the structure of the whole satellite. The two faces in the y, z plan have one half receiving low radiation dose and the other one receiving high dose. One possible explanation might be the presence of a hole at the bottom of the exterior wall in plan x,z. The side of the biologic experiment with more radiations corresponds to the side of the satellite with a hole. This means that this part is more directly exposed to radiations than the others which are protected by walls and other components that will be hit first by the particles.

In order to confirm this hypothesis and to make sure that these results are coherent and not due to a modeling mistake, the radiation penetrating thickness has been modeled too. As can be seen on figure 9, a similar distribution of the penetrating thickness values can be observed with values varying from 2.1 mm to 9.8 mm.The parts with a high radiation dose have a low penetrating thickness and conversely which confirms the hypothesis made previously.



3.4 Exterior walls

The study of the exterior walls is useful to confirm the previous results on the biologic experiment. In figure 11 the parts of the walls surrounding the hole in the x,z plan have higher radiation doses. They are indeed

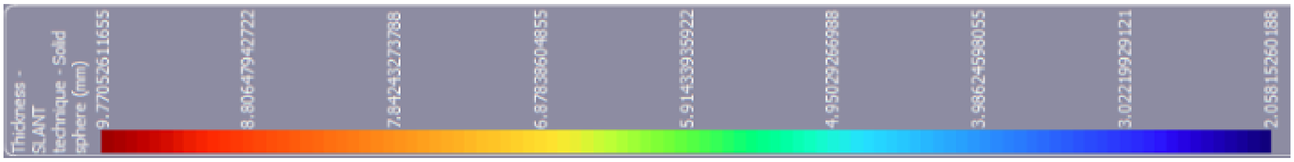


Figure 9: Radiation penetrating thickness on the biologic experiment at 640 km.

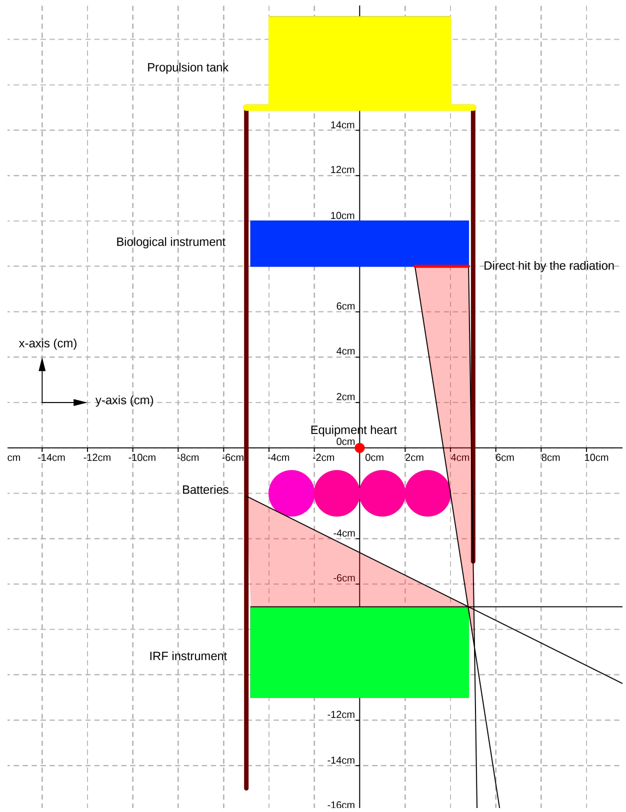


Figure 10: Profile view of the MIST model with direct radiation due to the hole in the exterior walls.

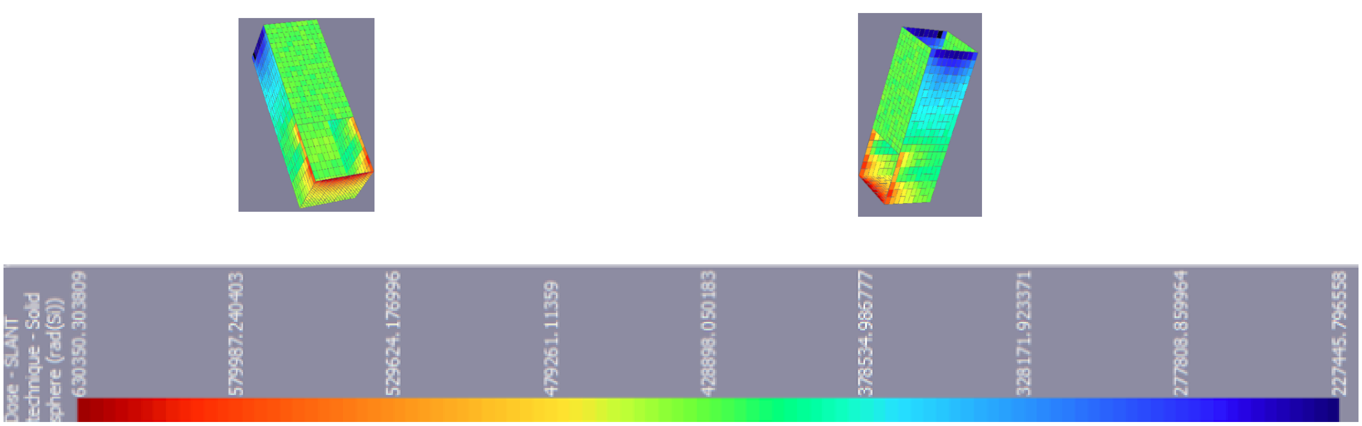


Figure 11: Radiation dose on the exterior walls at 640 km.

directly exposed to radiations that would be shielded if there were no hole. This highlights that radiations are entering directly into the satellite trough this hole.

The walls are not protected as the inner parts of the satellite which explains the higher values of dose than for the computer for instance. The dose can reach $6.30 * 10^5$ rad.

An other interesting point are the lowest dose areas on the top of the walls on two of the sides of the satellite. These are the sides with solar panels which are protecting the higher parts of the walls.

3.5 Batteries and IRF Experiment

The radiation dose model for the batteries and the IRF experiment show results quite similar to the biologic experiment. On figures 12 and 13, the parts of these two elements closer to the hole receive higher radiation doses.

More precisely, the face of the battery facing the bottom of the satellite, where the hole is, has higher values than the face facing which is protected with solar panels, walls, the propulsion tank and the biologic experiment.

On the IRF experiment the face in the (x,z) plan has the highest radiation dose values around $4.2 * 10^5$ rad which is pretty close to the values for the exterior walls.

An other interesting points is that the more an element of the satellite is close to the hole, the more is maximum value of radiation dose is high. The maximum for the biologic experiment is$2.7 * 10^3$ and is $4.2 * 10^5$ for the IRF experiment.

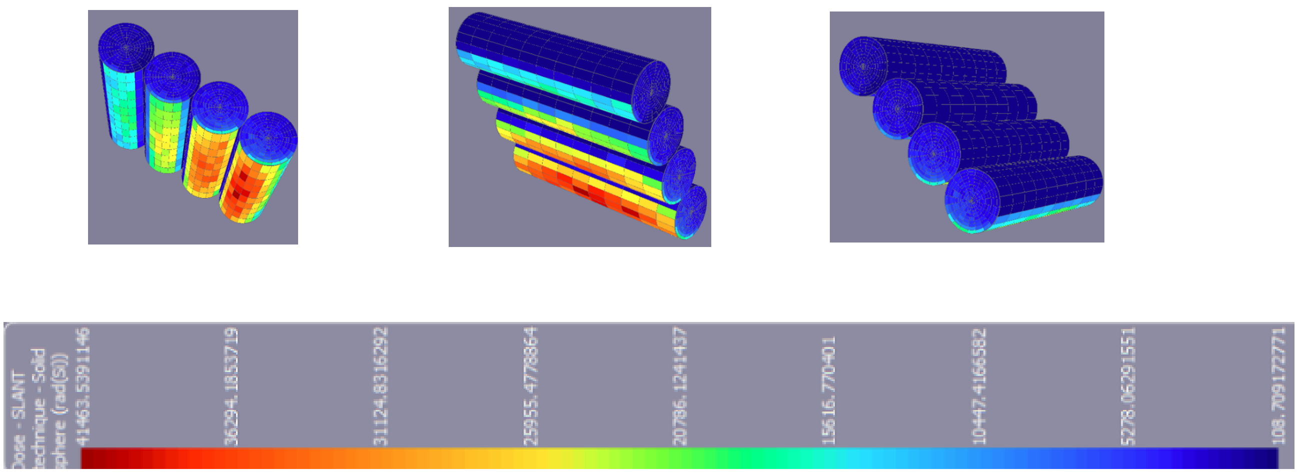


Figure 12: Radiation dose on the batteries at 640 km.

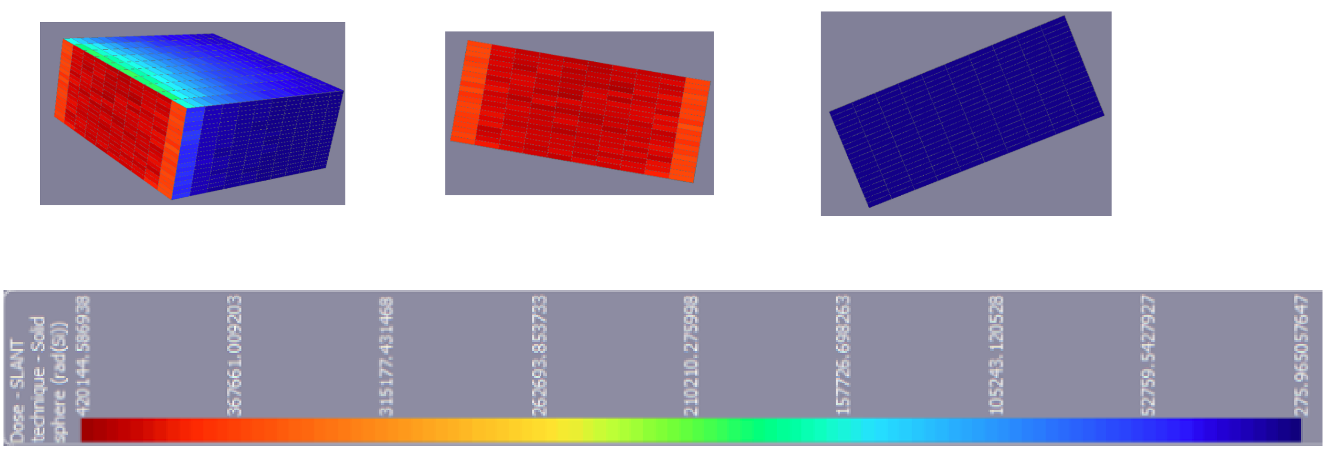


Figure 13: Radiation dose on the IRF experiment at 640 km.

3.6 Solar Panels

The radiation dose on the solar panels are shown in figure 14 and vary from around 834500 rad to 562960 rad. The inner parts of the solar panels are shielded by the other parts of the satellite while the outer parts are not. As expected the solar arrays are exposed to the highest radiations of the whole satellite.

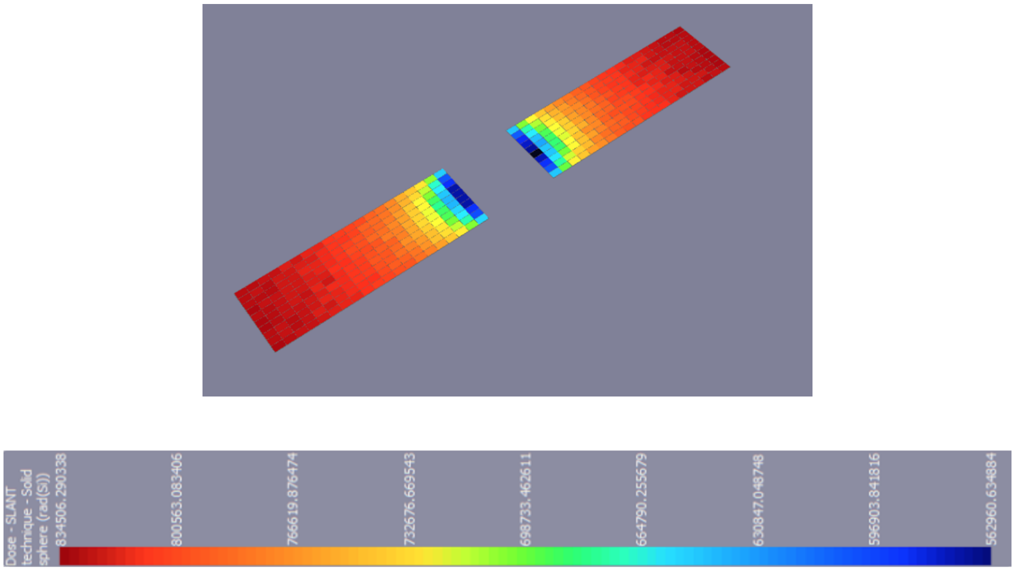


Figure 14: Radiation dose on the solar panels at 640 km.

3.7 CUBES Experiment

The CUBES experiment is a radiation intensity measurement of charged cosmic rays, X-/gamma-rays and neutrons on board MIST. Since the MIST satellite orbit will pass through the equator plane where low energy particles are found and through the polar region where high energy trapped particles. The detector is compromised of 3 silicon photomultiplier coupled to a 'GAGG' scintillator material. As one can observe from Figure 15, the detector is the heavily irradiated since it is positioned on the exterior of the spacecraft.

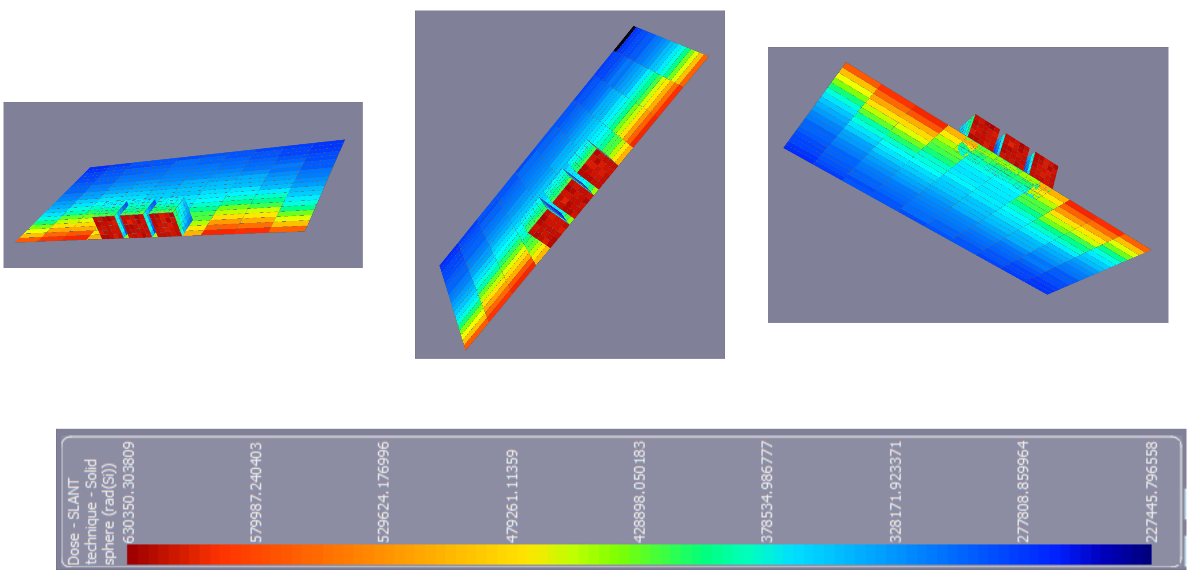


Figure 15: Radiation dose on the CUBES experiment at 640 km.

4 Analysis

The previous part has described the results of a radiation simulation on MIST. One of the main observations that have been made is that the placement of the equipment in the satellite has a huge effect on the radiation dose that the elements will receive.

Objects placed on the extremities are likely to receive high radiation doses as they are not protected by any other components and directly exposed to the radiations. On the other end the more sensitive equipment should be placed in the center where they will be shielded.

Deciding to keep one of the faces of the satellite open with a hole has also huge consequences on the doses of radiations that arrive inside the satellite and the effects of such a hole should not be neglected.

All these results highlight the fact that a radiation simulation should be part of the designing process of every satellite, such as the thermal radiation. Radiations received should determine the positions of the elements of the satellite in combination with their dissipated power and their functionalists. Wise choices such as placing solar panels on both sides of a satellite can help to limit the conditions that the satellite equipment will have to face.

5 Conclusion

This laboratory work showed that for a preliminary study of the radiation exposition of a satellite, it is enough to create a basic model of the spacecraft with its main features. The model we built enabled us to draw some conclusions on the absorbed dose of radiation from the different components we included in the model and, in further analysis was going to be performed, it would be possible to optimize the position of the components in order reduce the radiation on those ones which are more sensitive to it.

6 Division of work

J. Imbert Worked on and wrote the parts on biologic experiment, exterior walls, batteries and IRF and solar panels and analysis. Redaction of the introduction. Contributed to the parts "MIST model on Systema" and "Dose depth curves.

Y. Jiao Simulation setup; Redaction of the geometrical presentation and explanation.

F. Raiti Simulation setup; Redaction of "MIST model on SYSTEMA" and "Conclusion"

C. Muresan Simulation setup; Redaction of "Cubes" experiment.